Moored Observations of Nonlinear Internal Waves Near DongSha

Matthew H. Alford
Applied Physics Laboratory
1013 NE 40th Street
Seattle, WA 98105
phone: (206) 221-3257 fax: (206) 543-6785 email: malford@apl.washington.edu

Grant Number: N00014-05-1-0283
http://faculty.washington.edu/malford/

LONG-TERM GOALS

I am interested in the general problems of internal waves and the ocean mixing. Knowledge of these is important for advancing the performance of operational and climate models, as well as for understanding local problems such as pollutant dispersal and biological productivity. In the specific case of this DRI's focus, nonlinear internal waves (NLIW), the waves' currents and displacements are strong enough to impact Navy operations such as diving, ROV operation and mine detection/removal.

OBJECTIVES

- To understand the generation mechanisms, and predict the arrival times, of large NLIW in the northeastern South China Sea (SCS).
- To observe NLIW packets and estimate their energy and energy flux in the 2007 South China Sea experiment.
- To relate these to the energy and energy-flux in the low-mode tide, and to measurements of overturn-inferred turbulence.

APPROACH

Nonlinear internal waves are transient baroclinic phenomena where velocity and isopycnal displacements can be as large as 2 m/s and 150 m, respectively. The South China Sea, where they are particularly strong, was selected as one of the field-study regions for the NLIWI DRI in part because of the excellent historical context provided by the ASIAEX experiment (Ramp et al, 2004).

In planning the field experiment in the South China Sea component of NLIWI, Dongsha Island (in the western South China Sea, Figure 1) was identified as a location where the propagation, transformation and dissipation of the NLIW could be tractably studied, and a coordinated multi-PI experiment near DongSha Island in the western South China Sea to study it. Central to our study is the following hypothesis: *The low-mode internal tide propagates westward from Luzon strait in a narrow quasi-linear beam (Figure 1, arrows) aimed directly at Dongsha. When it reaches the steep continental slope, it steepens, nonlinearizes, and generates trains of nonlinear internal waves (NLIW's) that then propagate onto the shelf.* Considerable evidence, presented previously, supports this hypothesis;

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **Moored Observations of Nonlinear Internal Waves Near DongSha**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington,Applied Physics Laboratory,1013 NE 40th Street,Seattle,WA,98105**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**10**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

notably the occurrence of the strongest SAR signatures of NLIW's (orange lines) in the vicinity of this beam, near our study site at DongSha Island.

WORK COMPLETED

My portion of the project was to deploy two profiling moorings (Figure 1, 2) to measure the energy and energy flux of the NLIW and the internal tides. This portion of the project has been completed, and initial analysis completed as described in last year's annual report. No additional work has been done since funding for the analysis phase of this project has not yet been awarded.

RESULTS

Since the analysis funding has not arrived, no additional results past those shown in last year's report are reported. As requested, this report describes the work planned when funding arrives, which is also described in the analysis proposal. For concreteness, some of the figures from the proposal are included here.

Analysis will proceed in the following three veins:

• *Energy budget of waves and NLIW.* With the intensive mooring array and the shipboard work (Figures 1, 2), we have a realistic chance of "closing" an energy budget and identifying the energy pathways from the barotropic tide, to internal tide, to NLIW, to eventual dissipation. Since there is a period of several weeks when all moorings are concurrent (Table 1), the energy can be done in both a statistical sense (mean flux over long periods) and on a wave-by-wave basis. For this analysis, the internal tide energy flux estimates from the moored profilers, which are much more precise than those from conventional fixed-depth moorings, will be key.

• *Mixing of shoaling internal tides.* The strong diurnal dissipation signals observed at the continental slope (Figures 3, 4) are of sufficient magnitude to remove 10-20% of the incoming energy, making them important enough to impact the above discussion. However, the specific processes governing these large overturns are also of great interest and widely relevant owing to the great number of locations where internal tide energy impinges on slopes. Hence, Pinkel, Klymak and I propose to combine my observations, their shorter but more intensively sampled observations at 700 m, and the MITgcm model to understand the dynamics of the breaking process.

• *Wave timing.* Zhao and Alford [2006], Chris Jackson's work and the moored data (Figures 5, 6) suggest that a basic predictive understanding of the propagation of the waves from Luzon strait to the continental shelf has been achieved. However, many details remain uncertain including the dependence of the arrival time on stratification changes and mesoscale flow features such as Kuroshio intrusions. Together with Dr. Lien and Ming-Huey Chang, our data should be sufficient to answer this question. Dr. Chang may take the lead on this, but I anticipate being closely involved.

I anticipate that these analyses will together result in a coherent picture of the propagation, transformation and dissipation of internal tides and NLIW in the South China Sea.

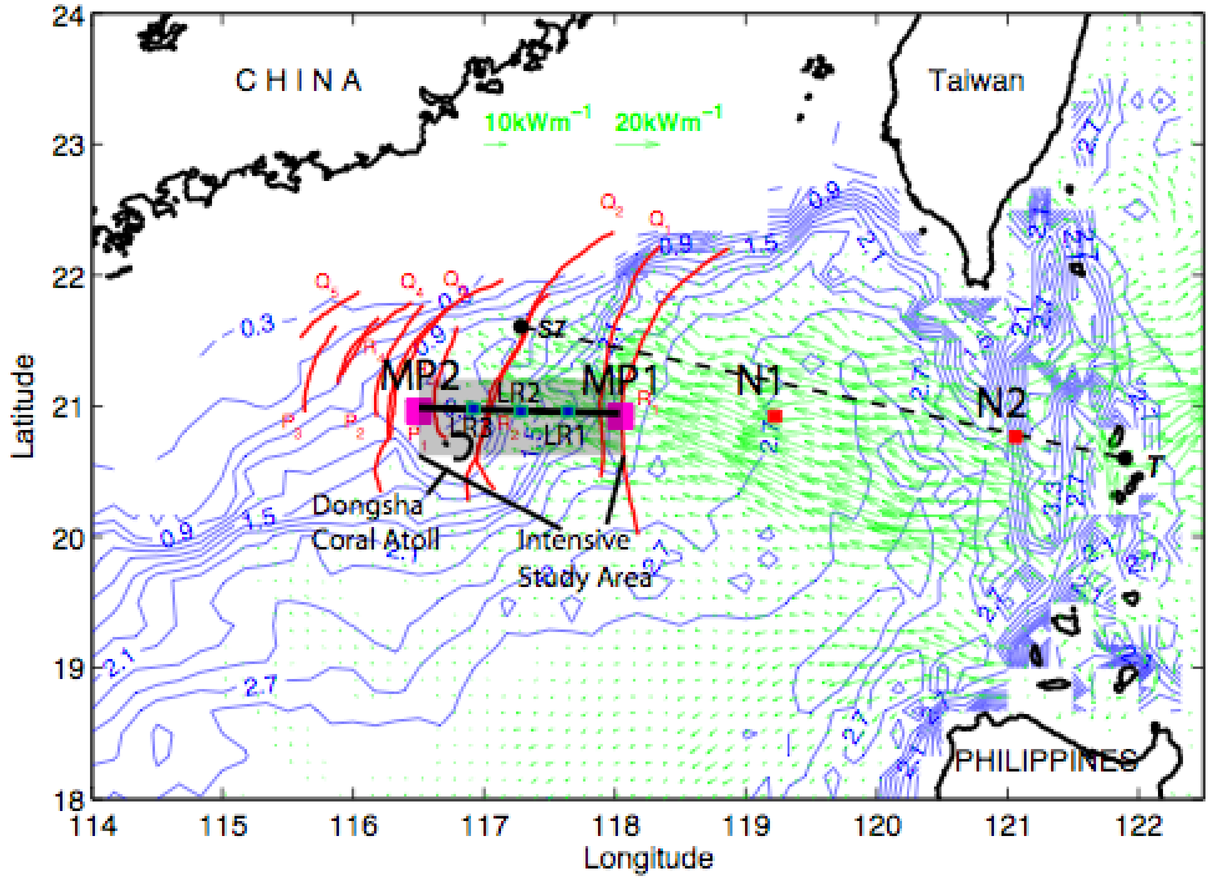

Figure 1: Depth-integrated M2 energy fluxes from a numerical simulation (Niwa and Hibiya 2004). The DongSha experiment (gray box) is sited in a beam of intensified energy flux from Luzon Strait (arrows), and in the region where the most SAR signatures have been detected (orange; Zhao et al, 2004). The moorings deployed during the experiment are indicated with dots.

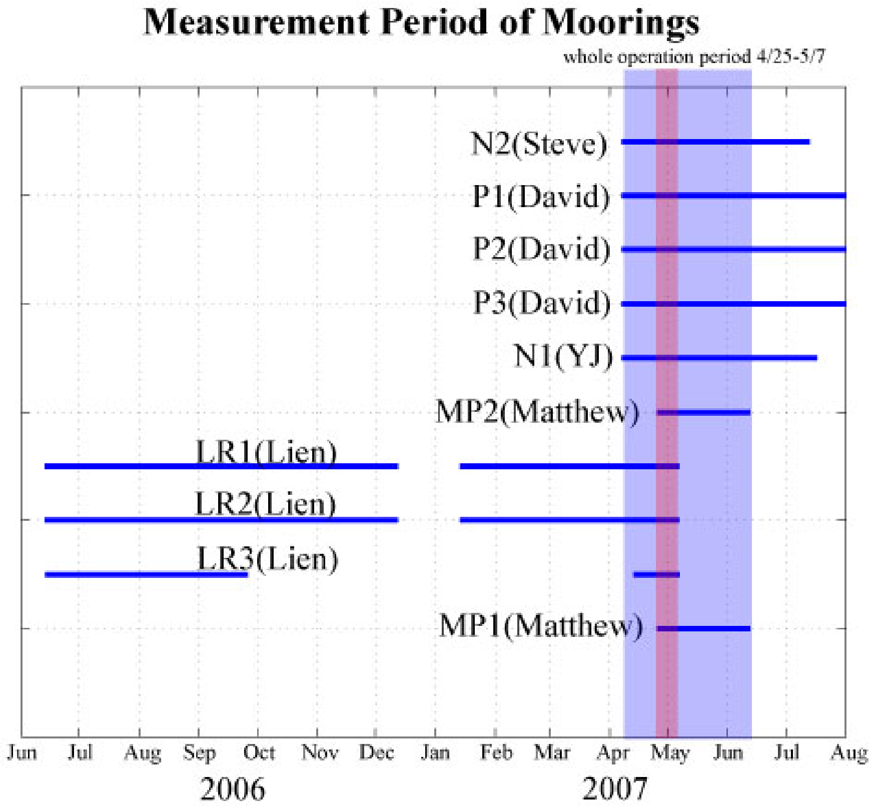

Table 1: A partial list of moorings deployed in the South China Sea during NLIWI.

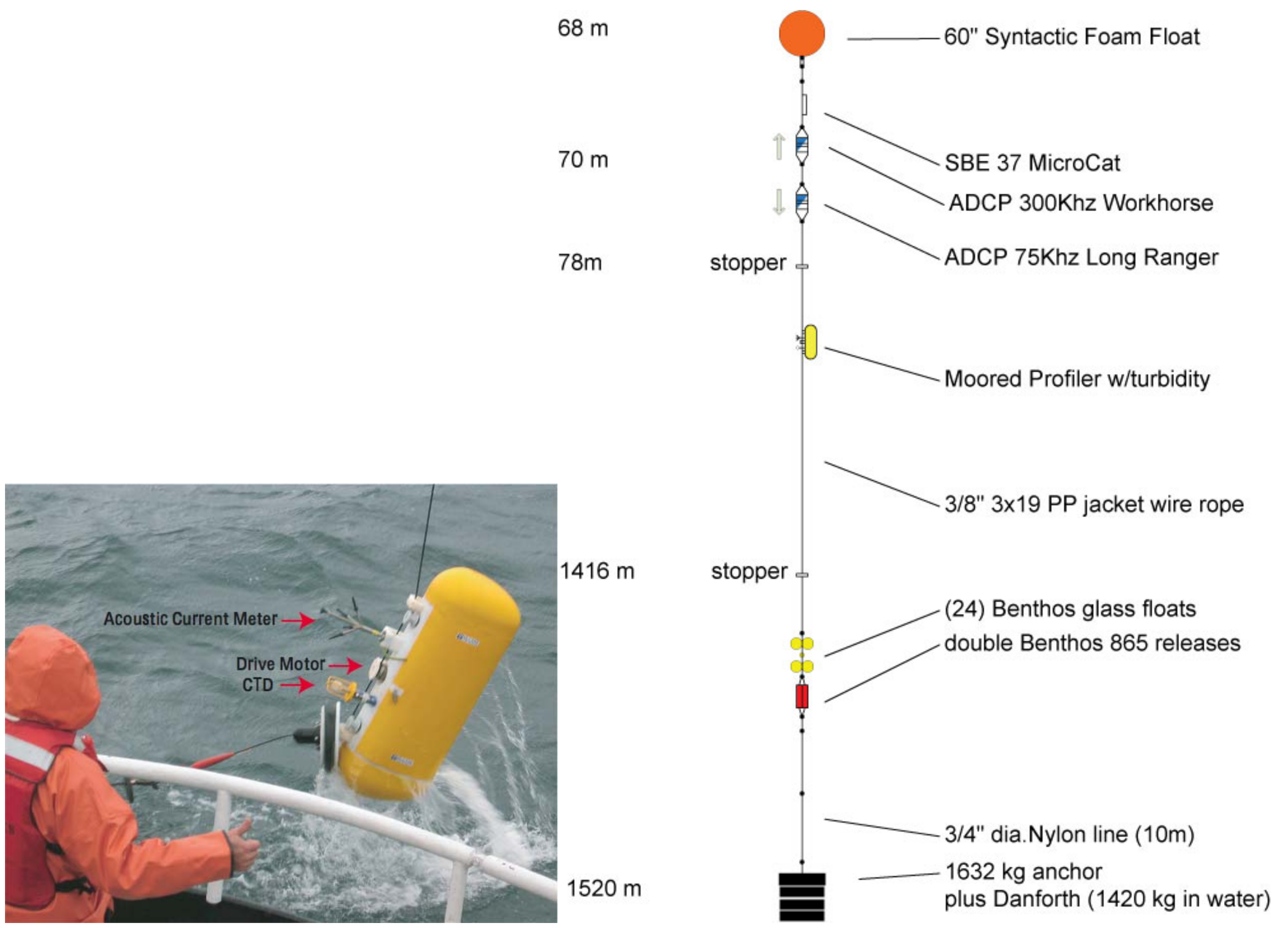

Figure 2: (Left) The McLane Moored Profiler being recovered in Puget Sound, WA. (Right) Mooring diagram at MP1. The uplooking ADCP did not function owing to a failed memory card. The shallow mooring at MP2 (not shown) is similar, with the MP sampling the range 60-300 m in 320 m of water.

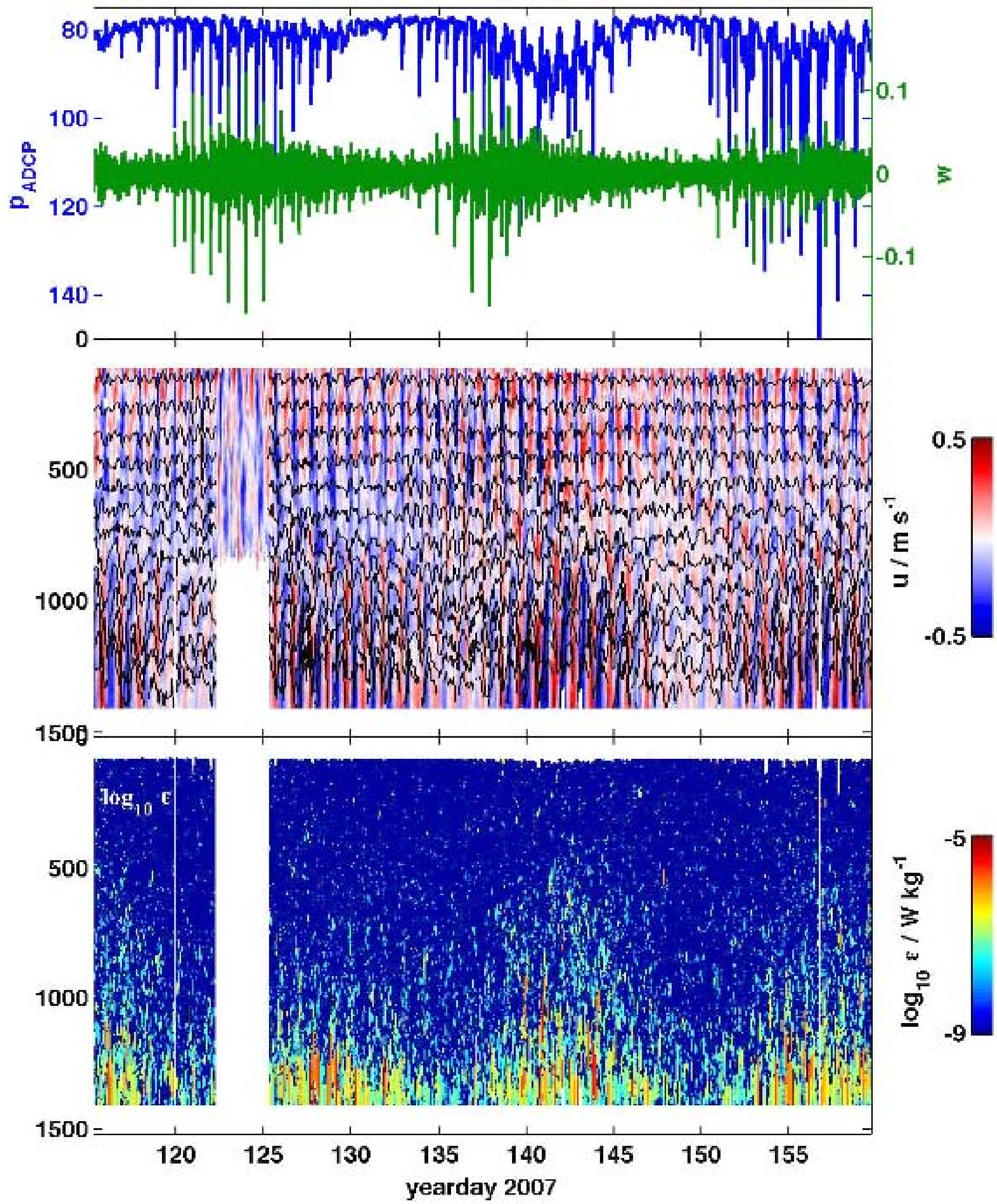

Figure 3: Summary of the 45-day mooring deployment at MP1. (top) Pressure measured at the top of the mooring (blue; axis at left) and vertical velocity measured at 200 m (green; axis at right). (middle) East-west velocity (colors) and isopycnal displacements (black). Velocities in the upper 800 m are from the 75 KHz ADCP; below that they are from the MP. (bottom) Turbulent dissipation rate, ε, measured from Thorpe scale analysis of density profiles from the MP. Current speed, dissipation, displacement, and the occurrence of waves all show clear spring/neap cycles. after westward current maxima (dashed lines).

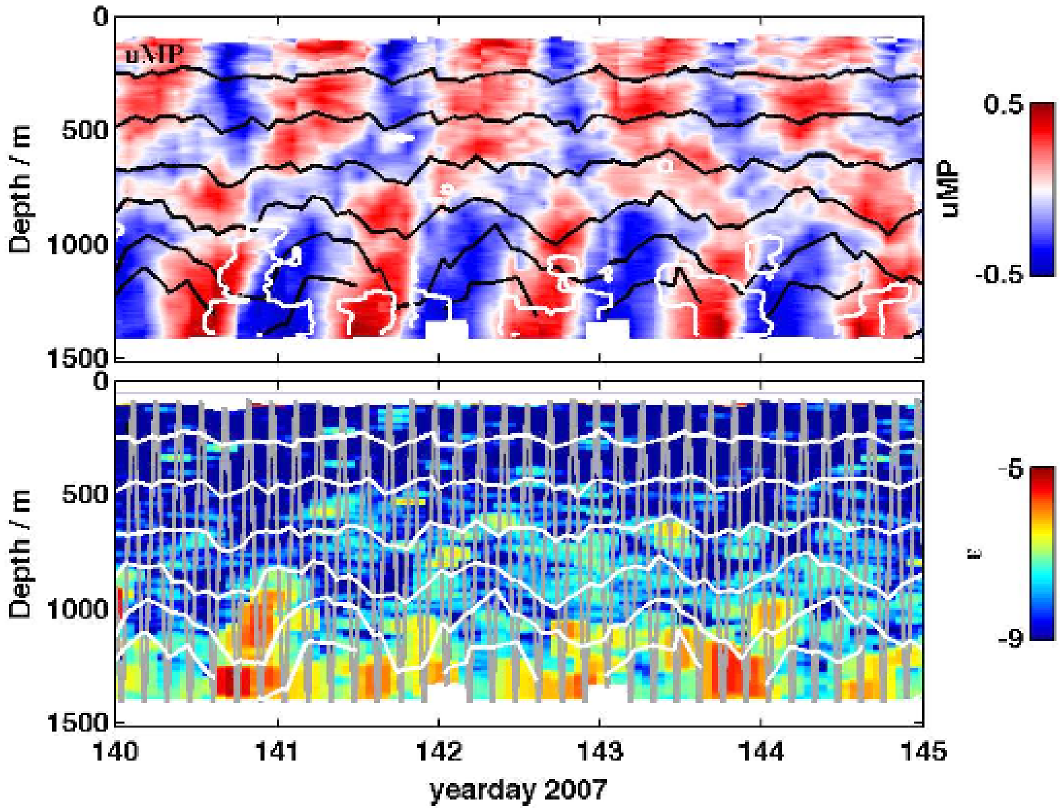

Figure 4: Velocity (top) and dissipation rate, (bottom) measured with the MP over a 5-day period during a spring tide. Isopycnals are overlaid. Regions of $\varepsilon > 10^{-6.5}$ Wkg^{-1} are outlined in white. Strong dissipations occur owing to strain events associated with diurnal internal tide motions on the sloping bottom. The moored profiler track (bottom, gray) indicates that these motions are well resolved.

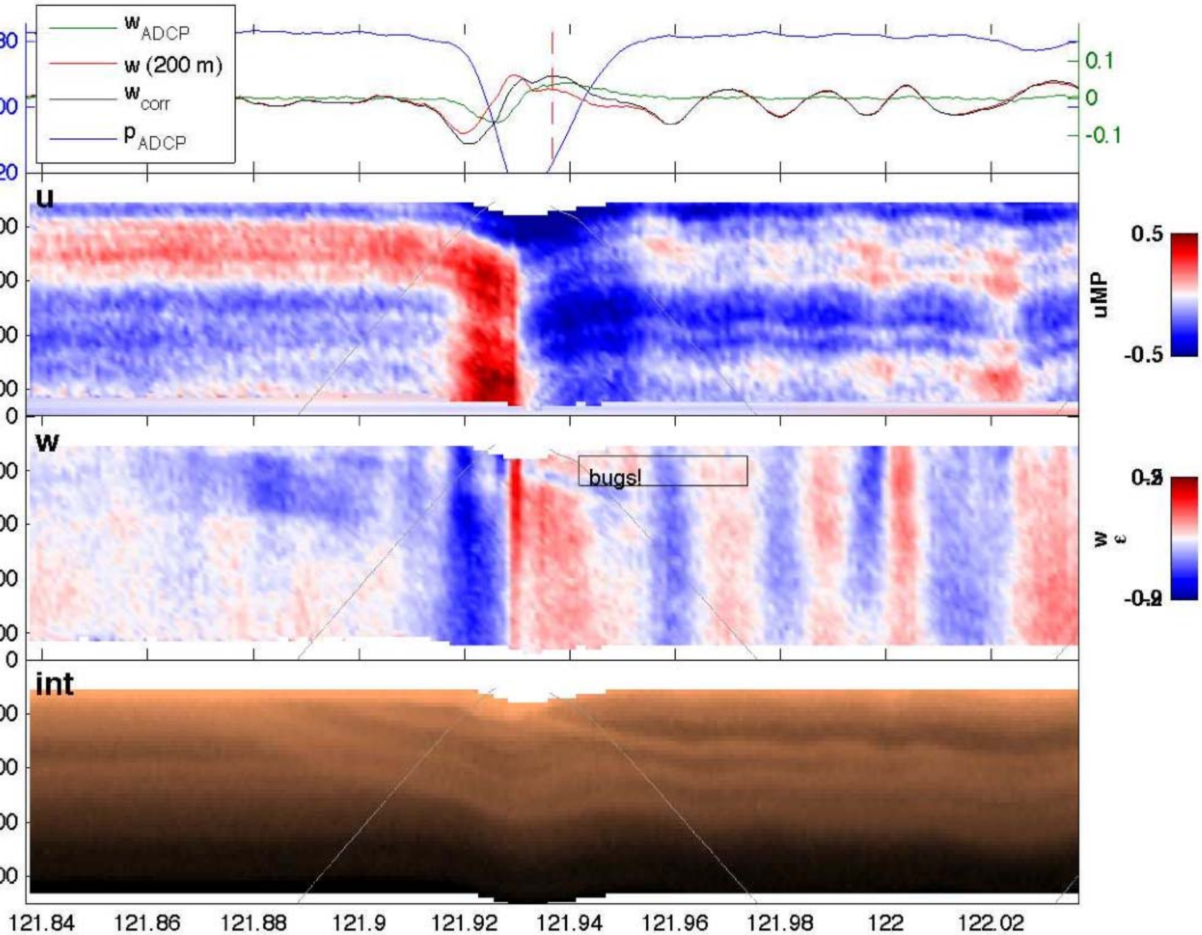

Figure 5: A sample wave event detected at MP1. A 2.5-hour period is plotted of only the upper 800 m. (top) Depth of the ADCP (blue; scale at left), showing drawdown of the mooring as the wave passed, and the vertical velocity measured by the ADCP at 200 m (red; scale at right). It is straightforward to correct measured signals using the measured mooring motion to produce a corrected vertical velocity (green). The associated u, w and intensity signals are shown below. Note the spurious vertical velocity signals associated with vertically migrating scatterers. The gray lines in the lower panels show the path of the moored profiler, indicating its coarse temporal resolution.

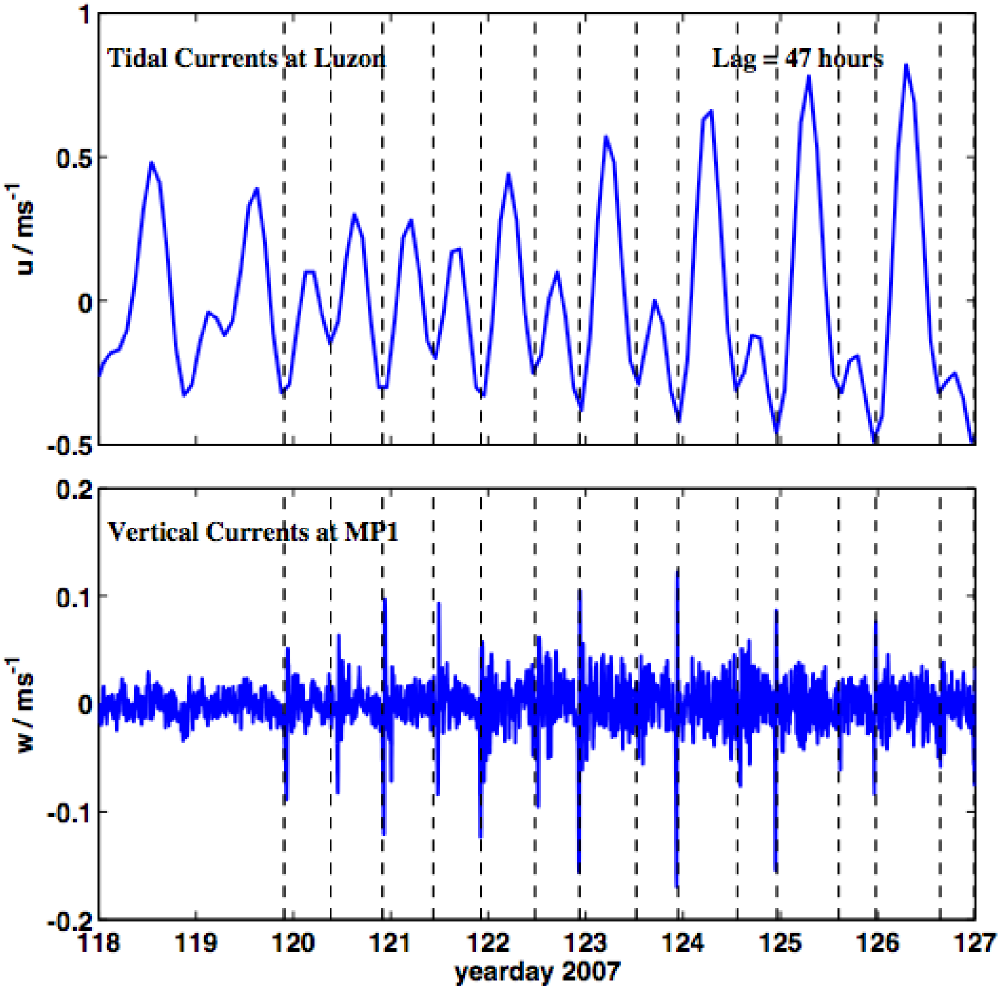

Figure 6: (top) Tidal currents at Luzon Strait. As in Figure 5, tidal currents are lagged by 47 hours. (bottom) Vertical velocity at 200 m measured at MP1. Waves occur 47 hours after westward current maxima (dashed lines).

IMPACT/APPLICATIONS

This rich dataset is only part of a large body of data collected during 2006 and 2007 by US and Taiwanese investigators. It is clear that the data will support an increased understanding of the timing, energy budget, and dissipation mechanisms of both the internal tides and the nonlinear internal waves. Ongoing efforts, closely coordinated with the other PI's, will seek to unravel these issues.

TRANSITIONS

RELATED PROJECTS

Work once analysis funding arrives will be closely coupled with Drs. Lien and Chang (APL), Simmons (UAF), Ramp, and St. Laurent (FSU).

REFERENCES

Niwa, Y., and T. Hibiya, Three-dimensional numerical simulation of M2 internal tides generated around the continental shelf edge in the East China Sea, J. Geophys. Res., 109, doi:10.1029/2003JC001,923, 2004.

Ramp, S. R., D. Tang, T. F. Duda, J. F. Lynch, A. K. Liu, C. S. Chiu, F. Bahr, Y. R. Kim, and Y. J. Yang, Internal solitons in the northeastern South China Sea, part I: sources and deep water propagation, IEEE J. of Oceanic Engr., 2004.

Zhao, Z., and M. H. Alford, Source and propagation of nonlinear internal waves in the northeastern South China Sea, J. Geophys. Res., 111, doi:10.1029/2006JC003,644, 2006.

Zhao, Z., V. Klemas, Q. Zheng, and X. Yan, Remote sensing evidence for baroclinic tide origin of internal solitary waves in the northeastern South China Sea, Geophys. Res. Lett., 31, doi:10.1029/2003GL019,077, 2004.

PUBLICATIONS

No articles have been published this year on this project.